(1)

# AUTOGENEOUS FRICTION STIR WELD LACK-OF-PENETRATION DEFECT DETECTION AND SIZING USING DIRECTIONAL CONDUCTIVITY MEASUREMENTS WITH MWM EDDY CURRENT SENSOR

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Al 2195-T8 plate specimens containing Friction Stir Welds (FSW), provided by Lockheed Martin, were inspected using directional conductivity measurements with the MWM sensor. Sensitivity to lack-of-penetration (LOP) defect size has been demonstrated. The feature used to determine defect size was the normalized longitudinal component of the MWM conductivity measurements. This directional conductivity component was insensitive to the presence of a discrete crack. This permitted correlation of MWM conductivity measurements with the LOP defect size as changes in conductivity were apparently associated with metallurgical features within the first 0.020 in. of the LOP defect zone. Transverse directional conductivity measurements also provided an indication of the presence of discrete cracks. Continued efforts are focussed on inspection of a larger set of welded panels and further refinement of LOP characterization tools.

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# Autogeneous Friction Stir Weld LOP Defect Detection and Sizing Using Directional Conductivity Measurements with MWM™ Eddy-Current Sensor

## AeroMat Conference

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# Objective

- Demonstrate preliminary capability of the JENTEK MWM™ Sensor with Grid Methods to provide a measure of the lack of penetration (LOP) defect thickness for Friction Stir Welds


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# Specimens

Four panels with similar FSW geometry representing a range of LOP defect thickness:

- **No LOP defect**
- **0.02 inch thick LOP defect**
- **0.04 inch thick LOP defect**
- **0.09 inch thick LOP defect**



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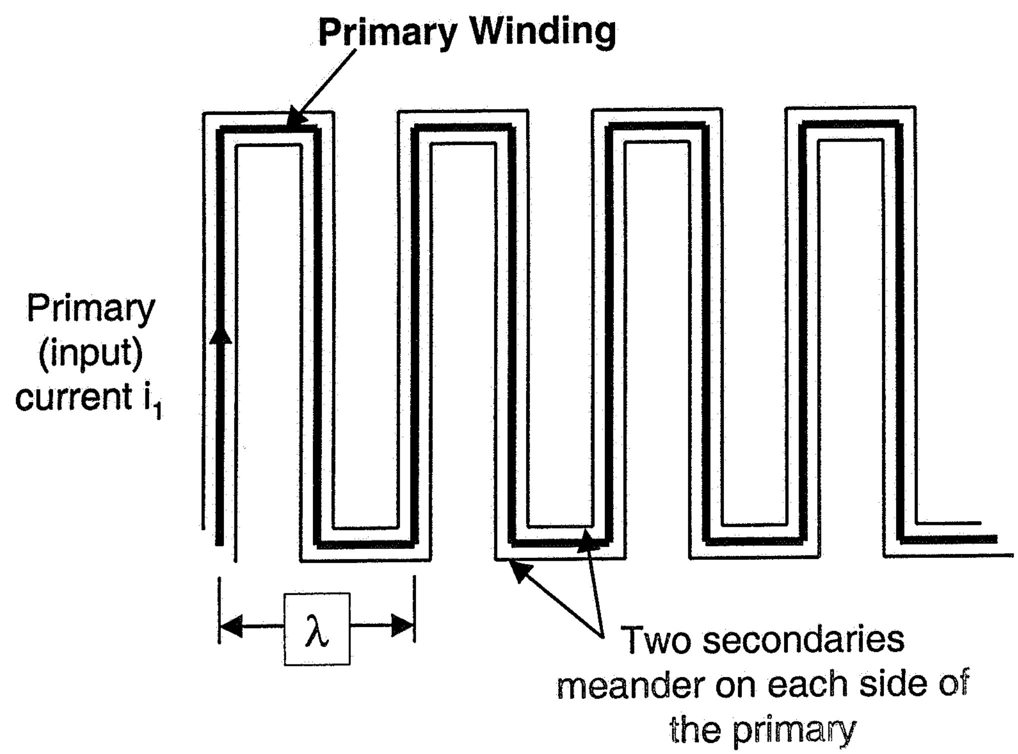
# MWM™ Measurements

- Single Frequency (250 kHz)
- Two-Dimensional images
- One-Dimensional “Line” scans
- Parallel and perpendicular orientation of MWM windings

# Meandering Winding Magnetometer




- Thin
- Conformable
- Surface Mountable
- Configurable into an array for imaging

**Transfer Impedance = Secondary Voltage / Primary (input) Current**



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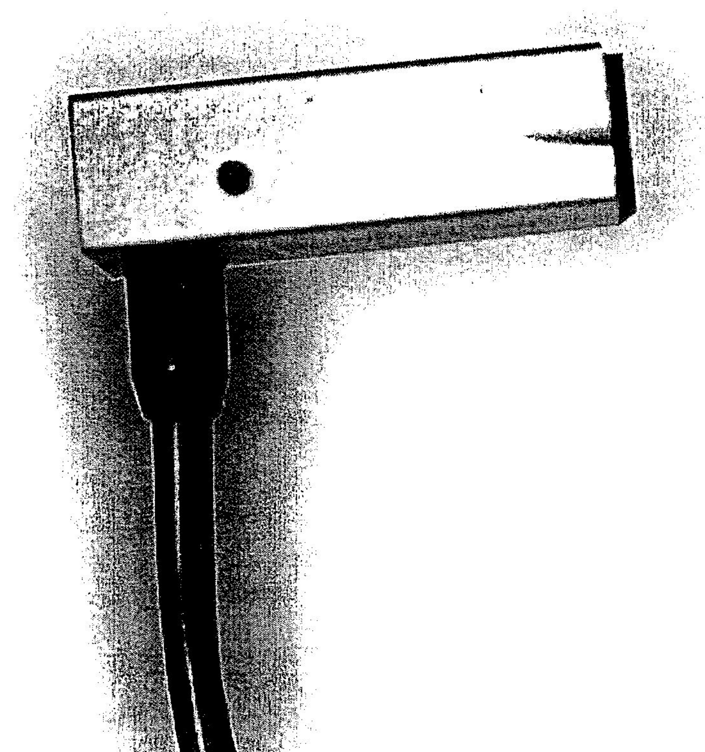
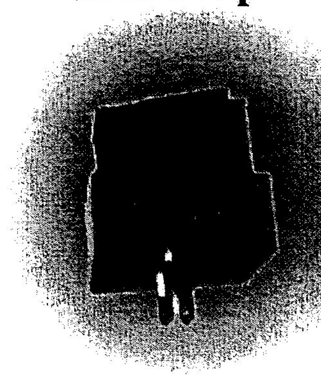
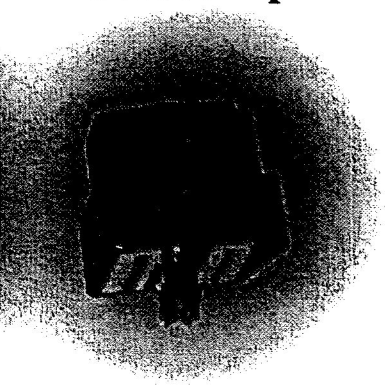
# MWM™ Probe and Replaceable MWM™-Array Sensor Tips

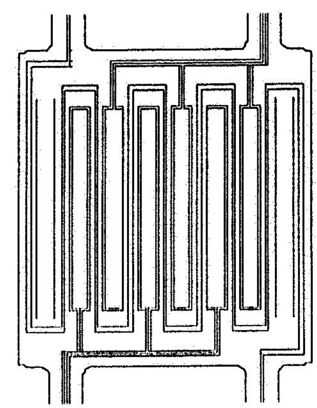


Calibration Shunt Tip



Sensor Tip





Single Sensing Element MWM Sensor



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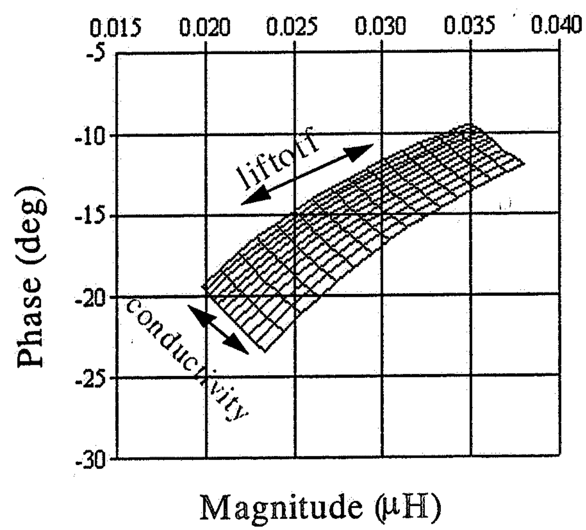
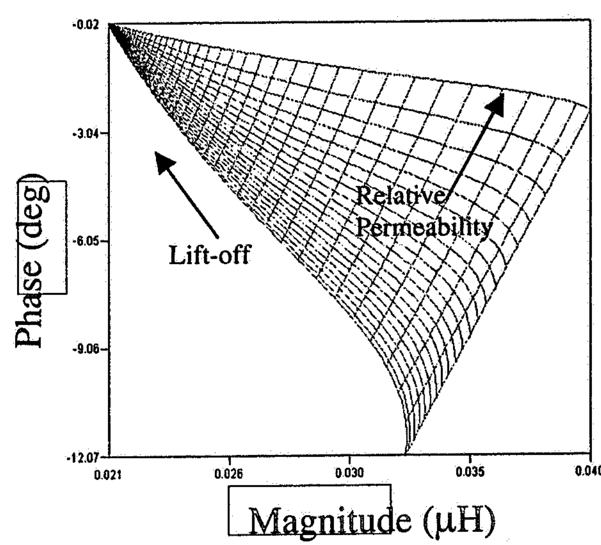
# Representative Measurement Grids

***These grids relate the magnitude and phase of the transimpedance to the liftoff, and***
***(a) conductivity for aluminum, and***
***(b) magnetic permeability for low alloy steel***

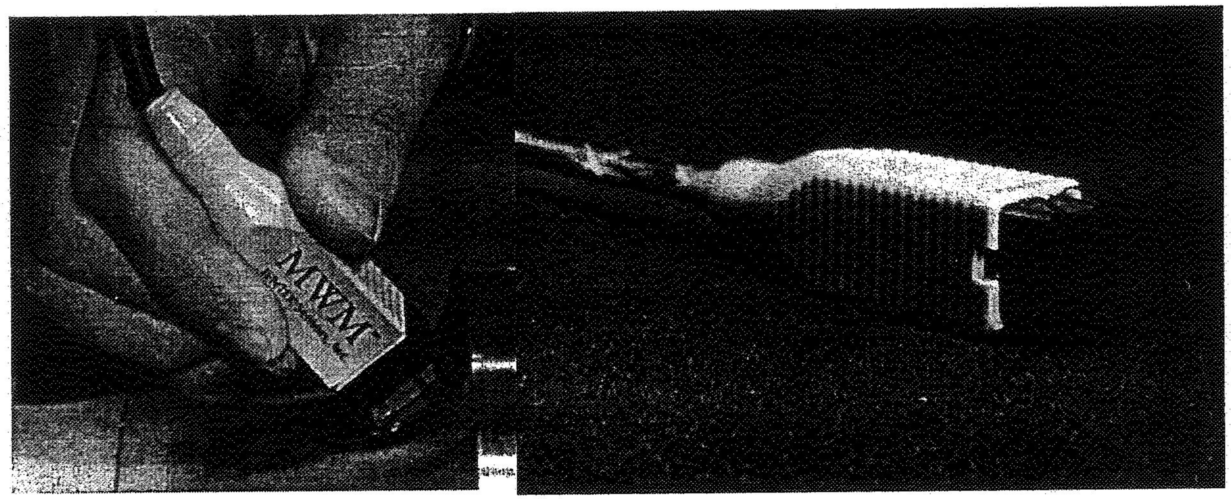



(a) Aluminum

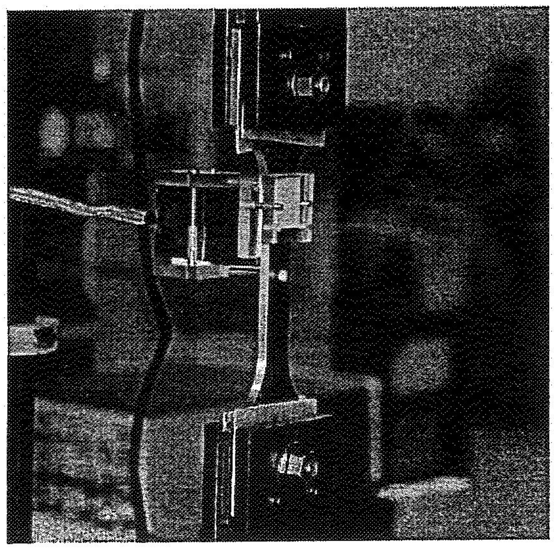



(b) Low-Alloy Steel

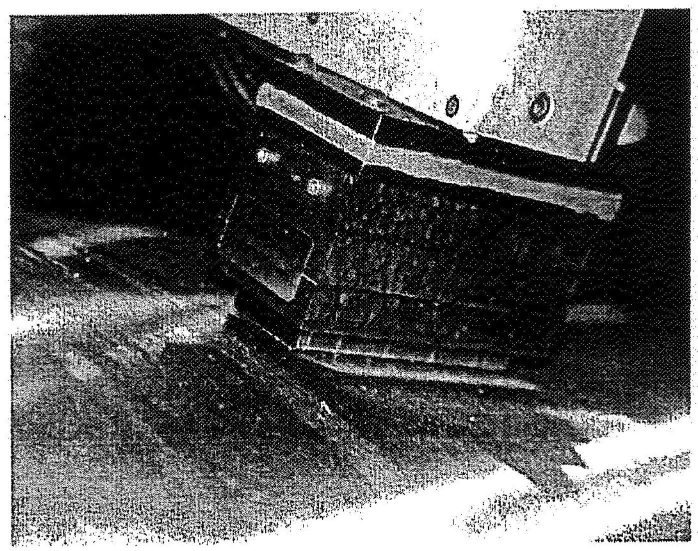
# MWM™ and MWM-Array Probes




Single Element Conformable MWM Probe for Flat and Curved Surfaces



MWM-Arrays for Continuous
On-Line Fatigue Test Monitoring
and In-Service Monitoring



MWM-Array for On-Line Contact or
Non-Contact C-Scan Imaging



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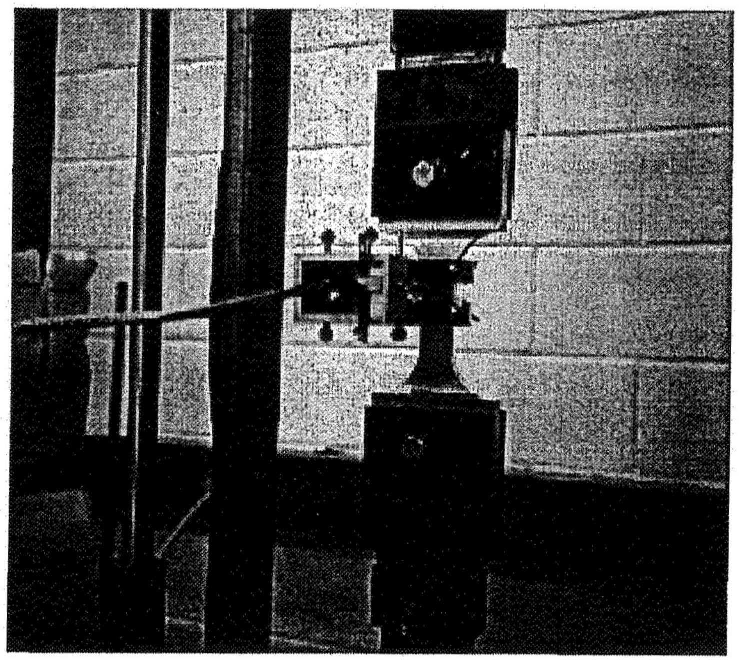
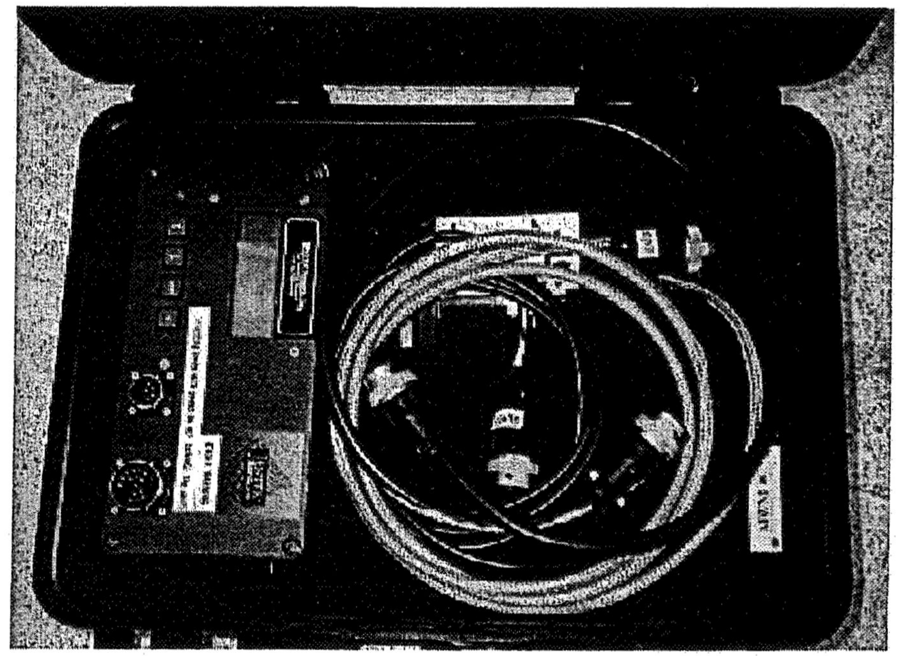
# New Portable JENTEK Mini-GridStation™

# MWM-Array On-Line



MWM-Array
mounted in .25 inch hole



Remote Instrument Module (RIM)
with on-line coupon fixture/cables

# Future Efforts

- Customization of an MWM-Array for scanning of FSW welds with an increased spatial wavelength to provide increased depth of penetration and high spatial image resolution for LOP detect mapping and crack detection
- Investigation of multiple frequency methods with a deeper penetration probe for differentiating small LOP defects below 0.03 inches (future effort)
- Investigation of the relationship between MWM responses and FSW microstructure variations
- Investigation of high temperature in-process MWM-Array monitoring of microstructure variations



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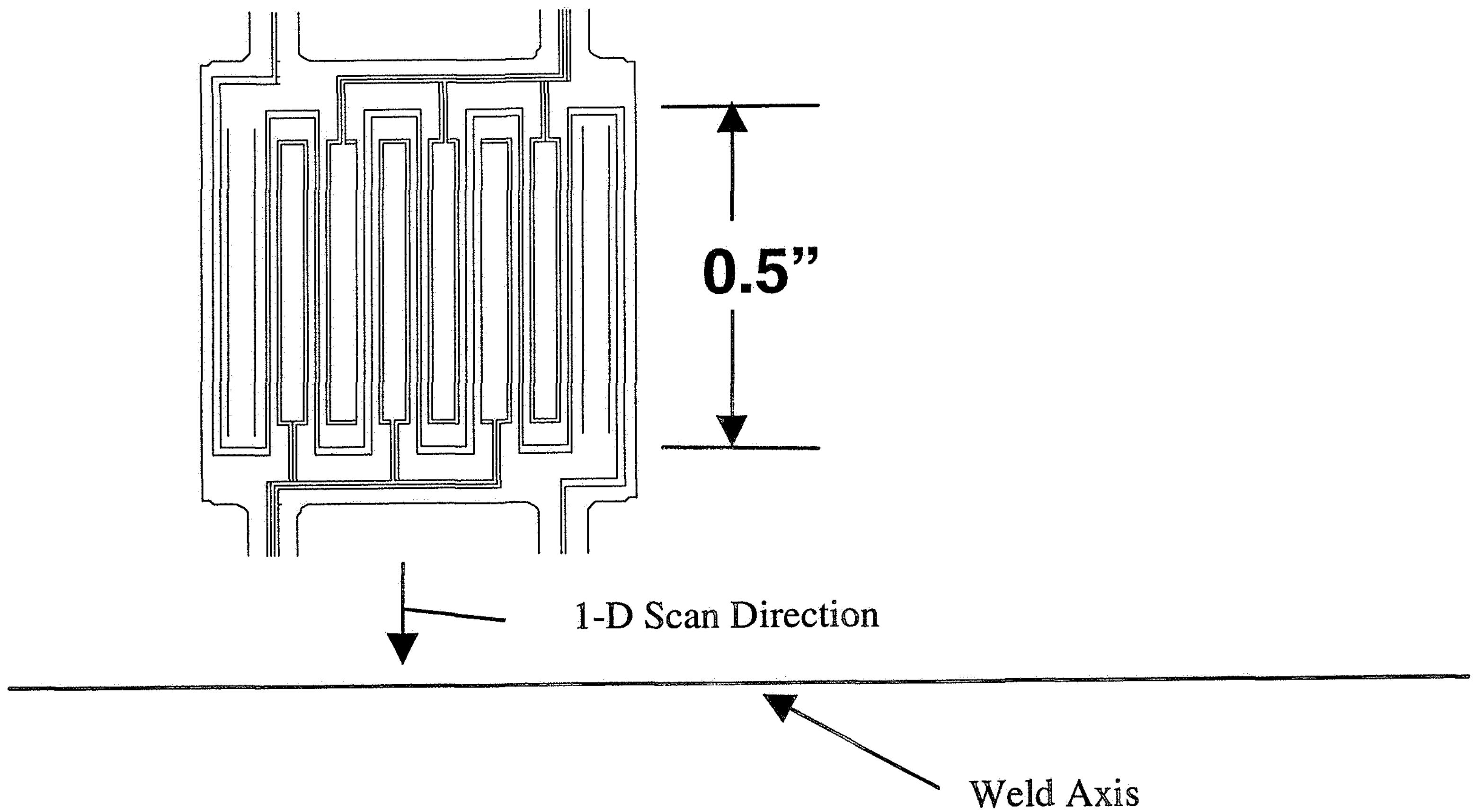
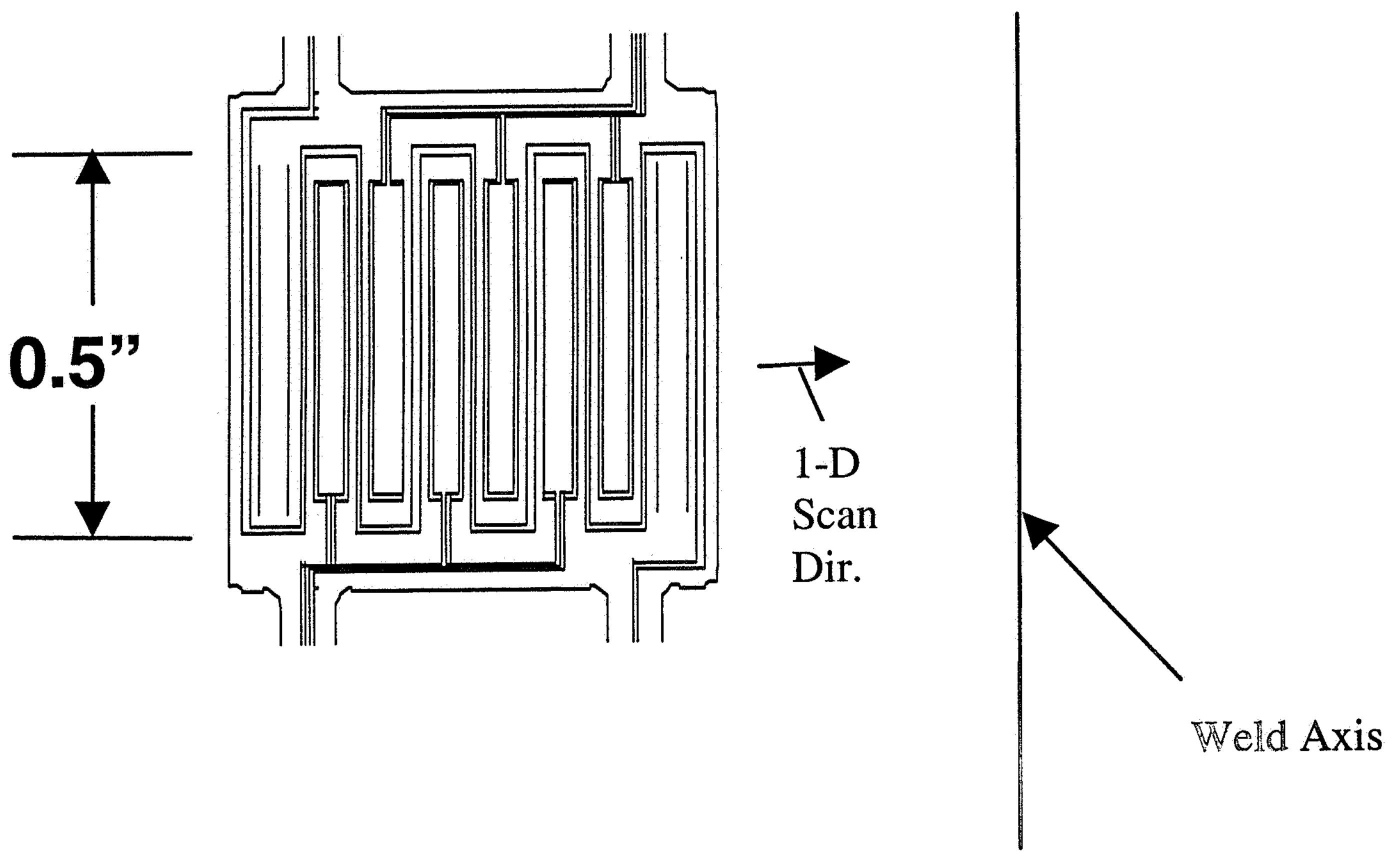
# MWM Probe and Scan Orientations Relative to Weld Axis

MWM with Perpendicular
Orientation Relative to Weld Axis



# MWM Probe and Scan Orientations Relative to Weld Axis

## MWM with Parallel Orientation Relative to Weld Axis



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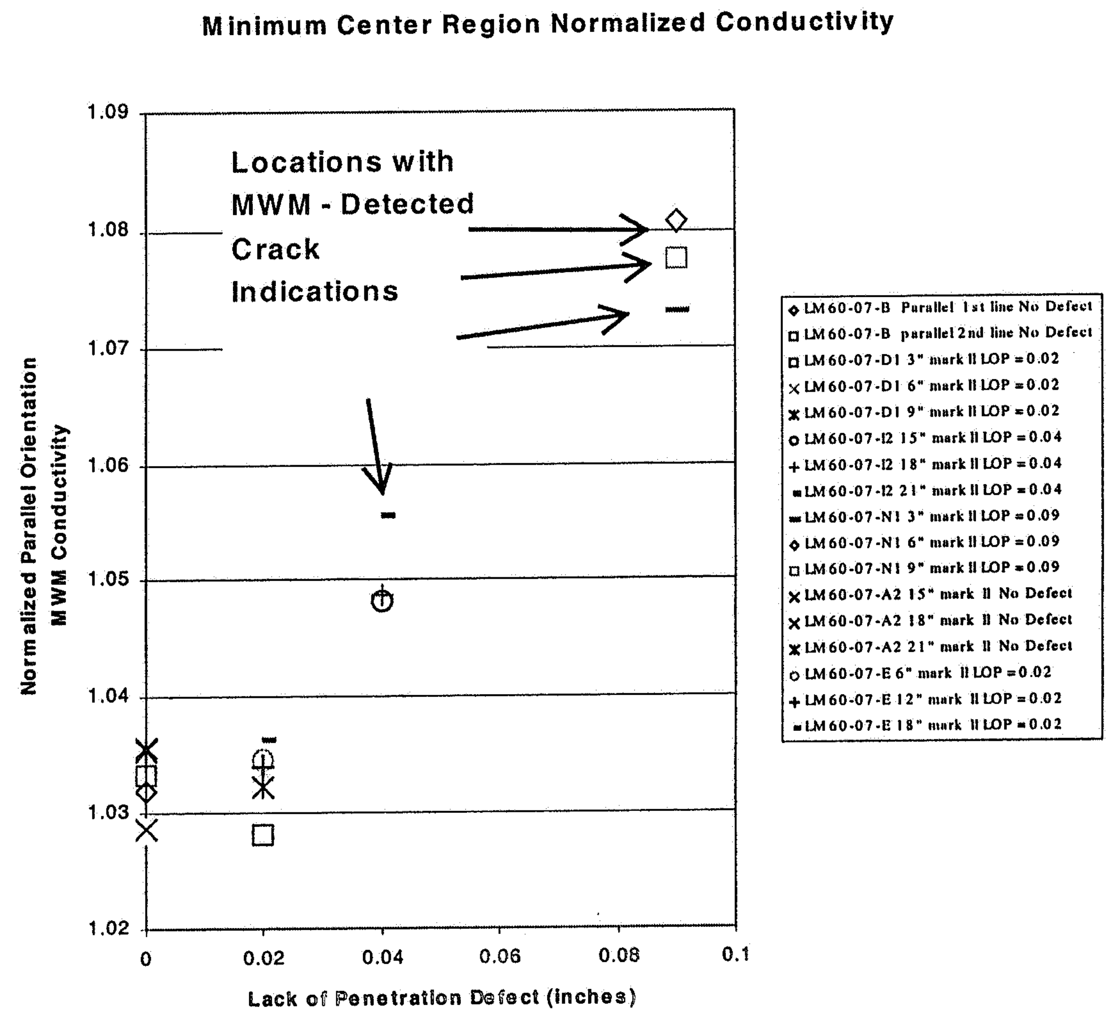
# MWM Sensor Response

## (Minimum Center Region Normalized Conductivity) as a Function of Lack of Penetration Defect Thickness







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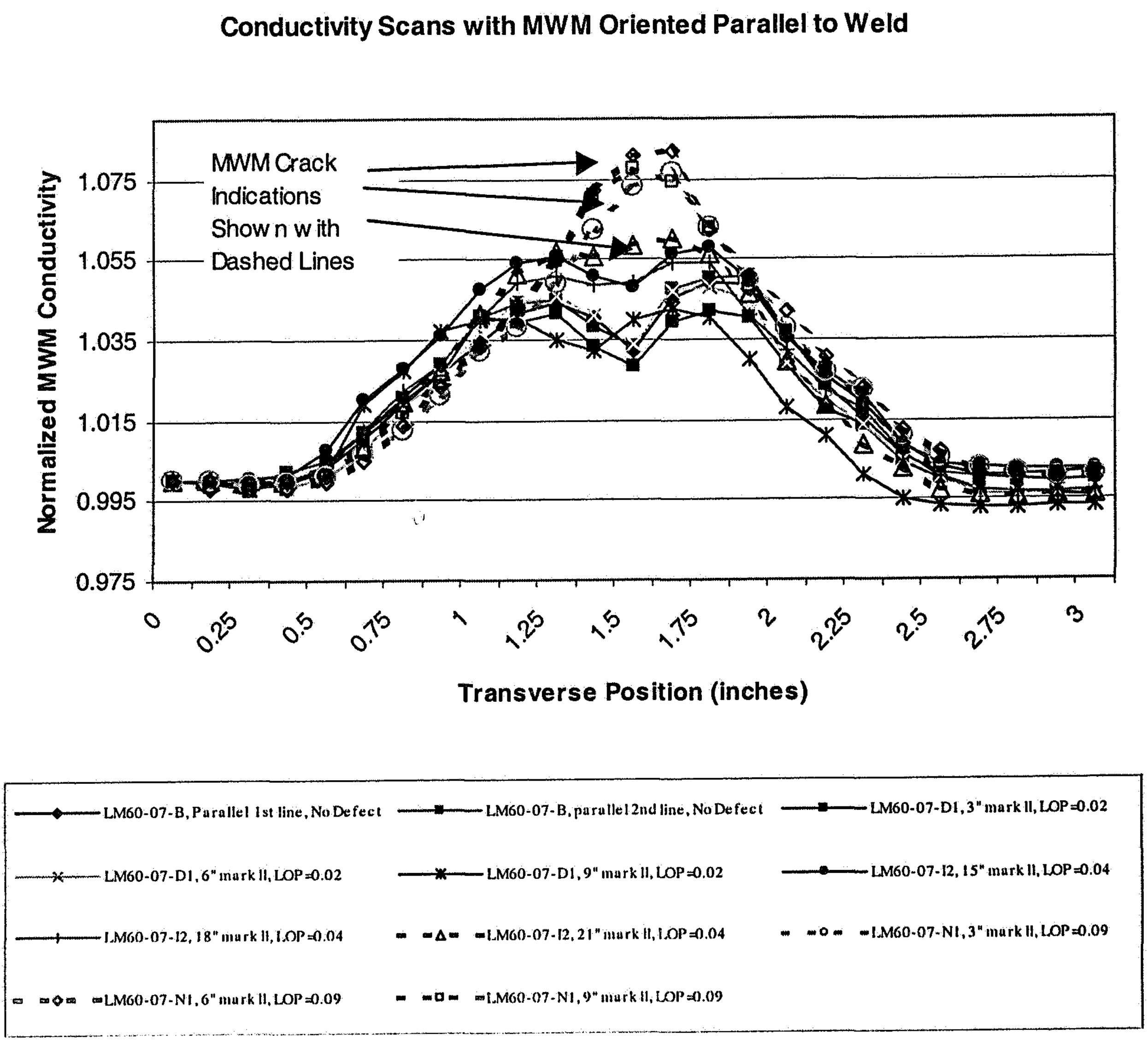
# Normalized MWM Conductivity Scans for Friction Stir Weld Specimens



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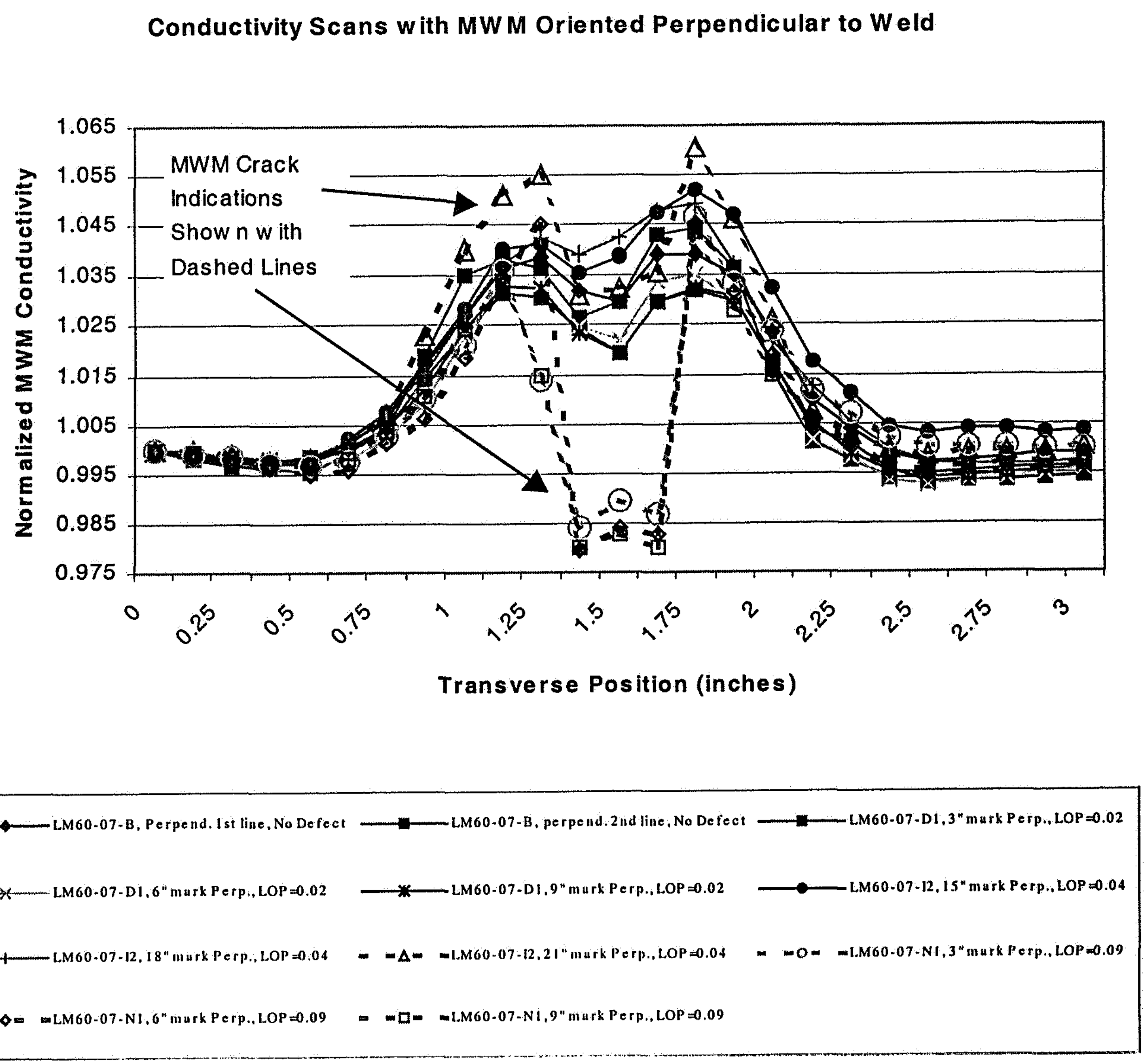
# Normalized MWM Conductivity Scans for Friction Stir Weld Specimens



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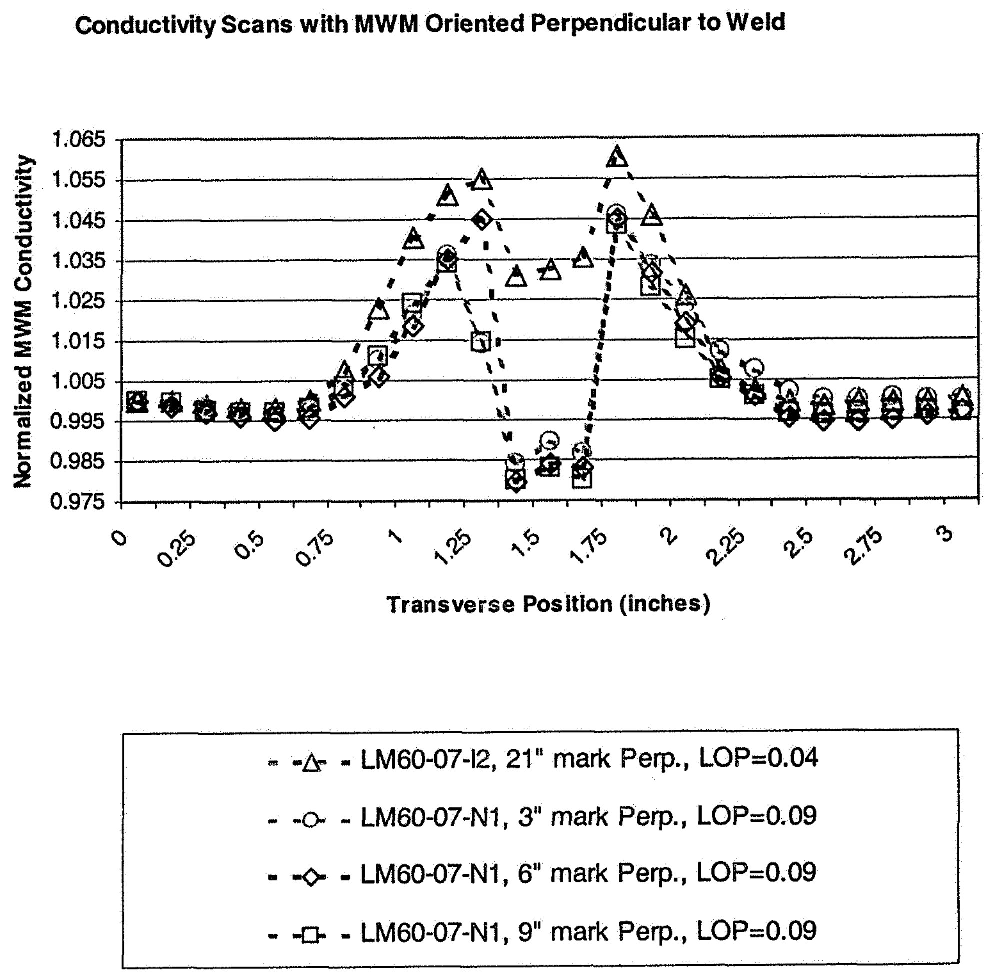
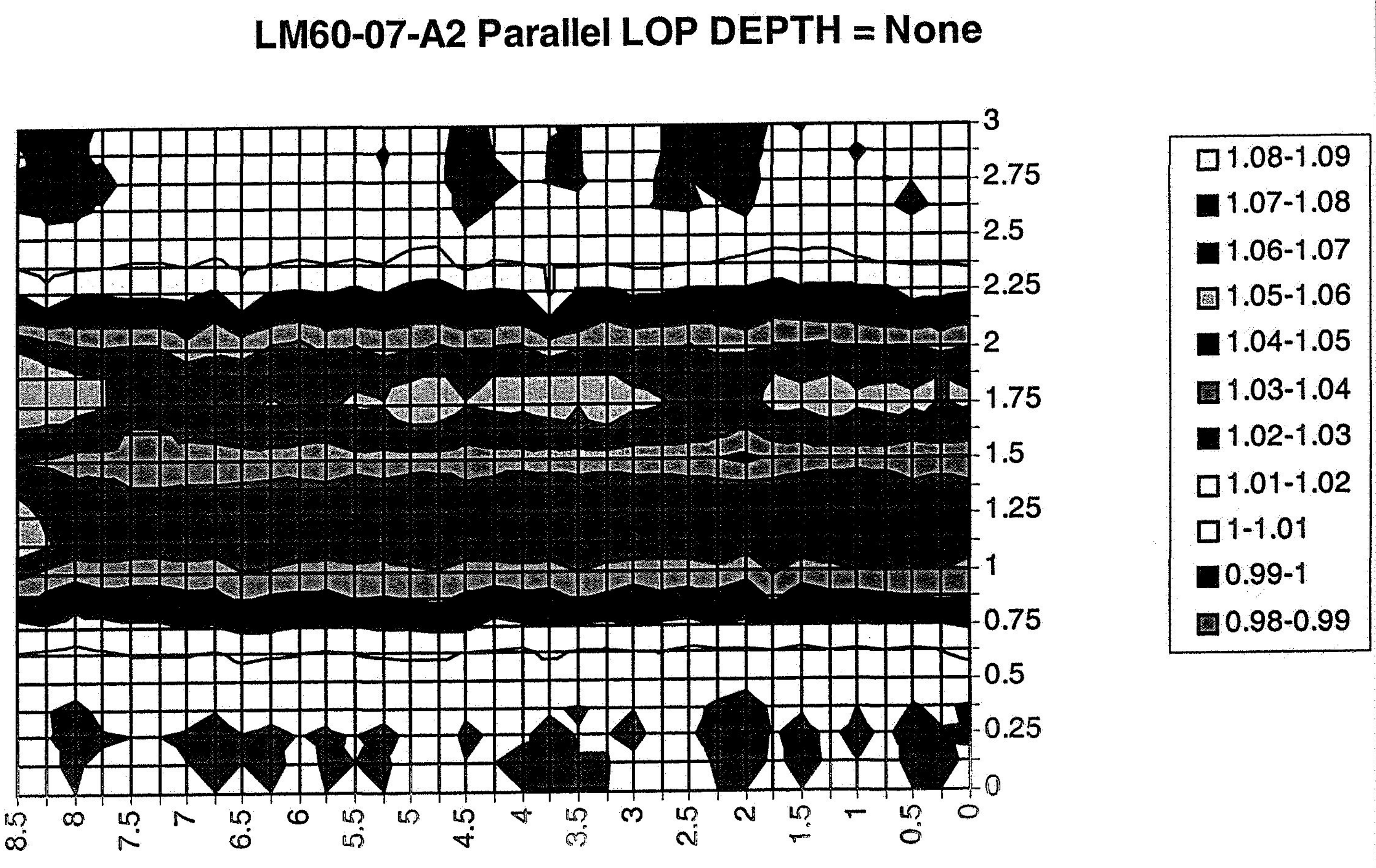
# Normalized MWM Conductivity Scans for Friction Stir Weld Specimens

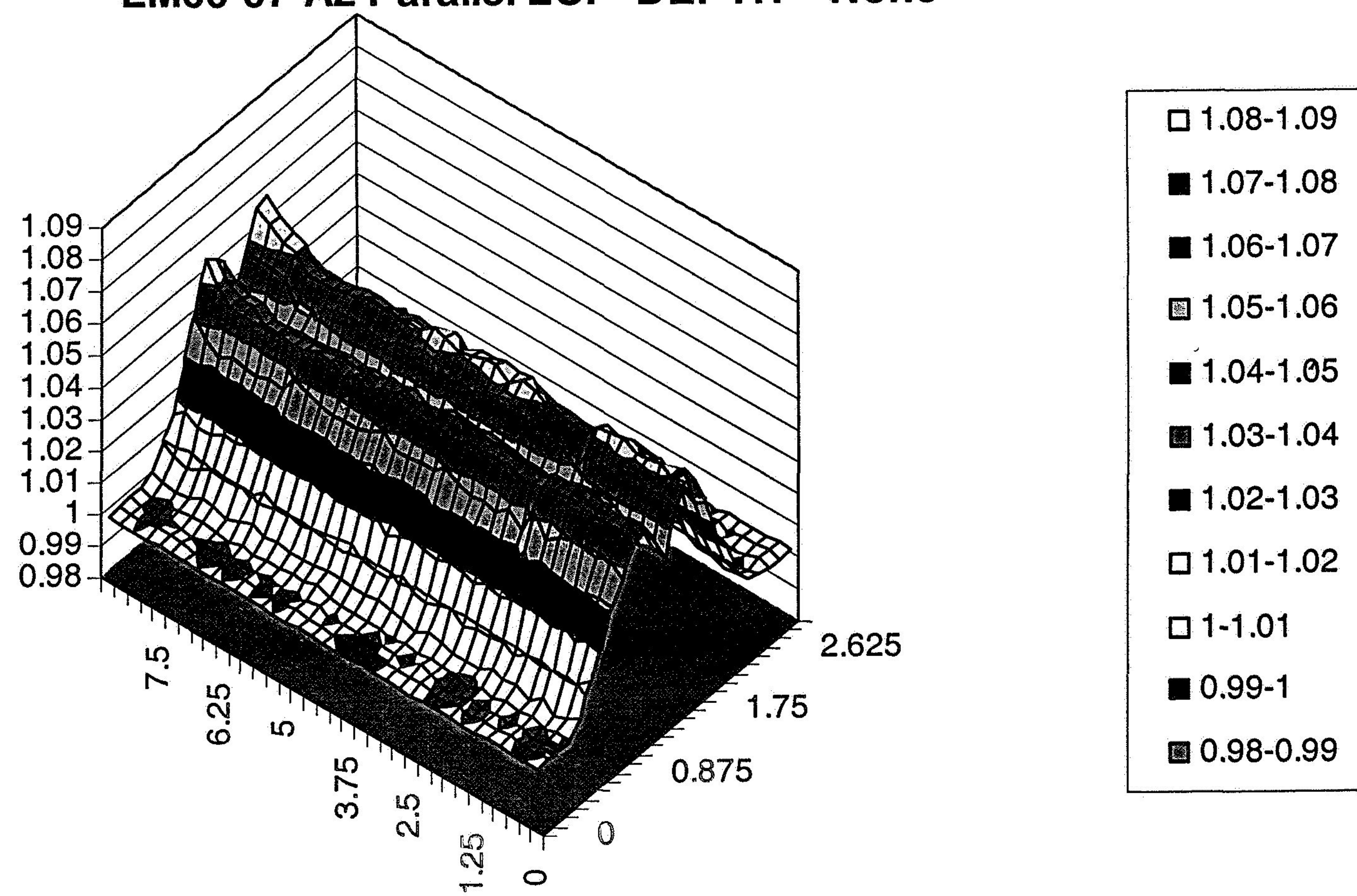



Only the locations with MWM Crack Indications, Determined by Perpendicular Scan Response Shape (e.g. three adjacent substantially reduced conductivity values, within 0.5% of each other) are shown in this figure.

# Normalized 2-Dimensional MWM Image of Specimen LM60-07-A2, at 250kHz, with MWM Longer Winding Segments Parallel to Weld Axis



# Normalized 2-Dimensional MWM Image of Specimen LM60-07-A2, at 250kHz, with MWM Longer Winding Segments Parallel to Weld Axis



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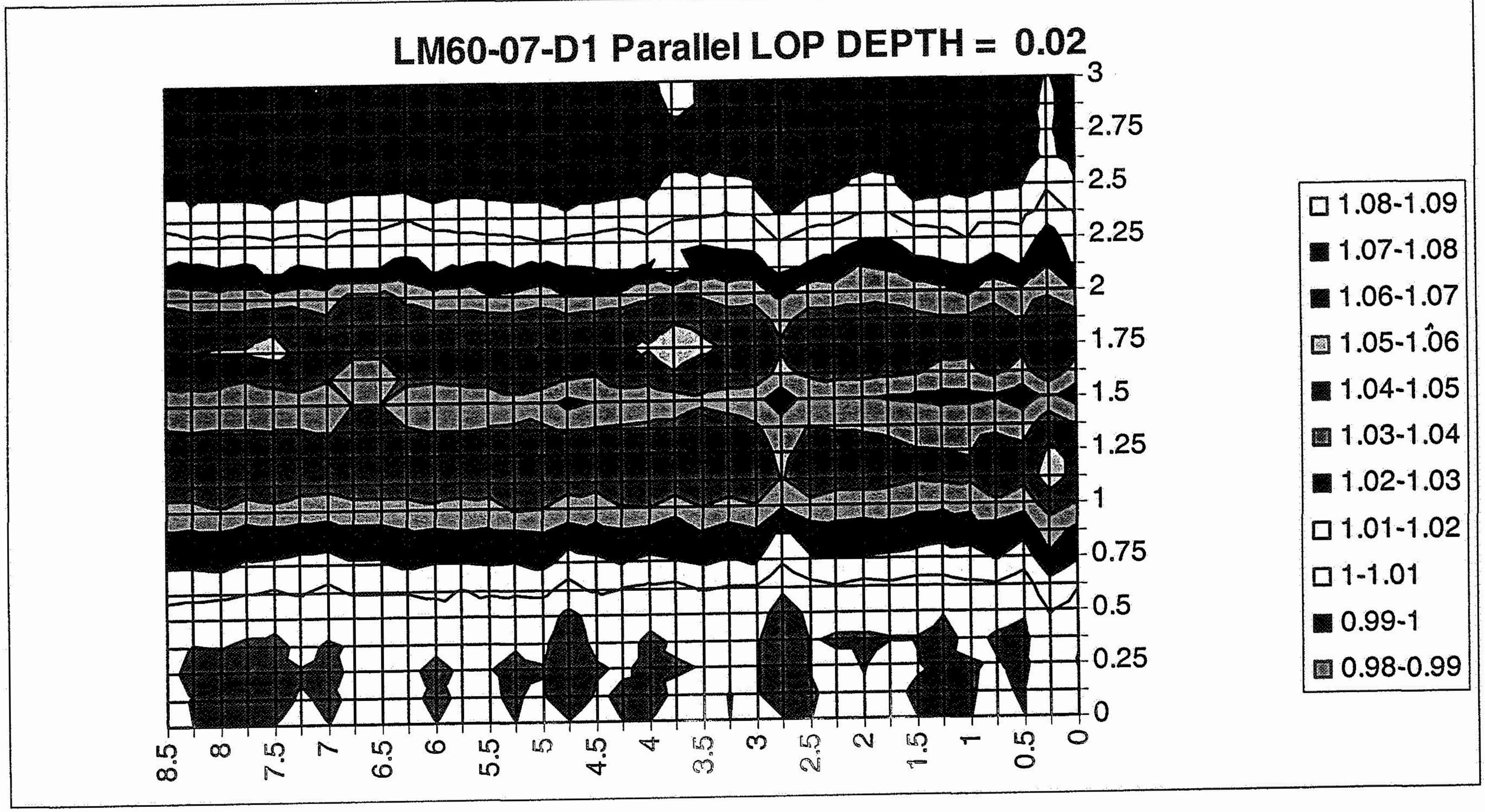
# Normalized 2-Dimensional MWM Image of Specimen LM60-07-D1, at 250kHz, with MWM Longer Winding Segments Parallel to Weld Axis







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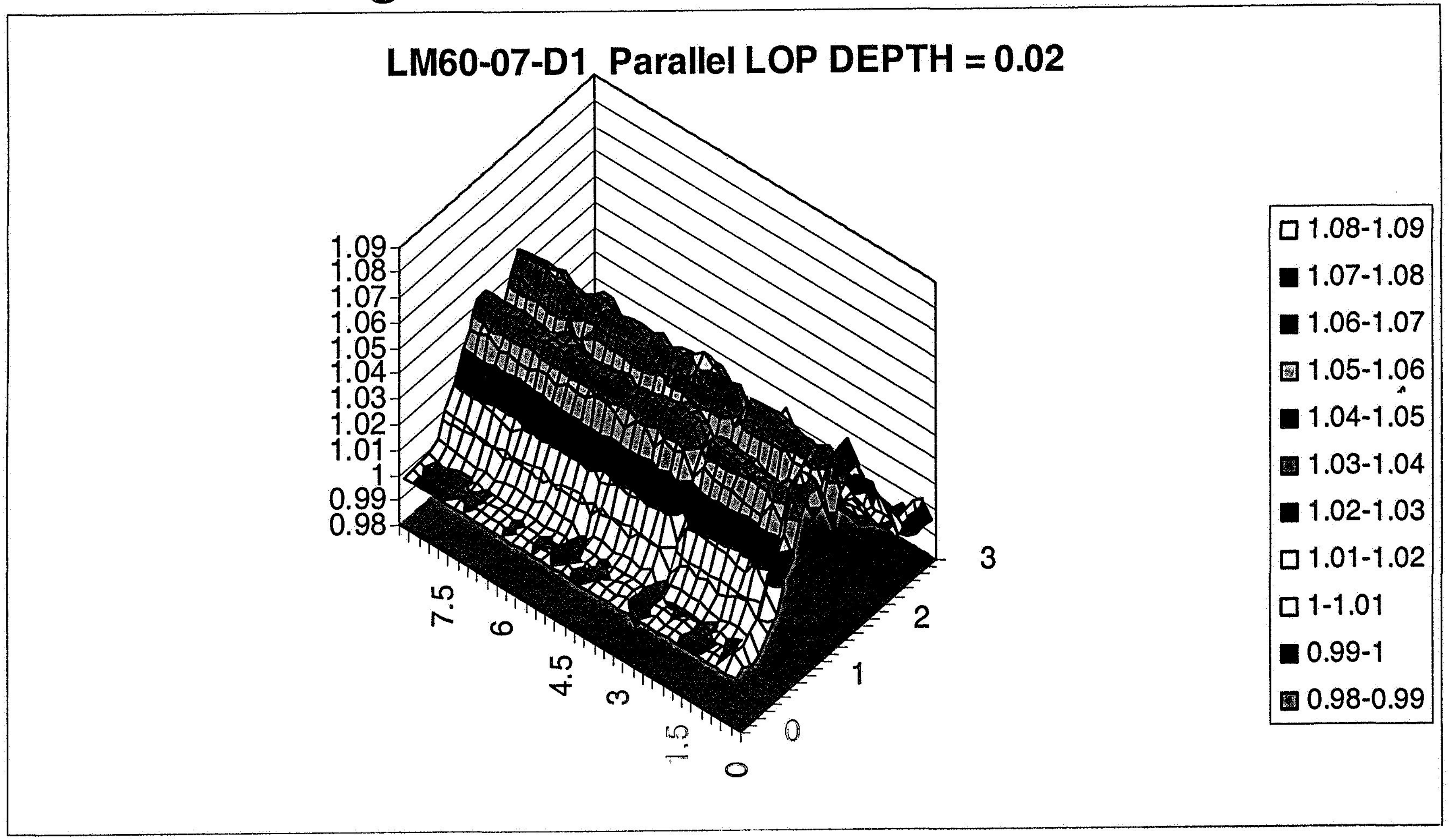
# Normalized 2-Dimensional MWM Image of Specimen LM60-07-D1, at 250kHz, with MWM Longer Winding Segments Parallel to Weld Axis







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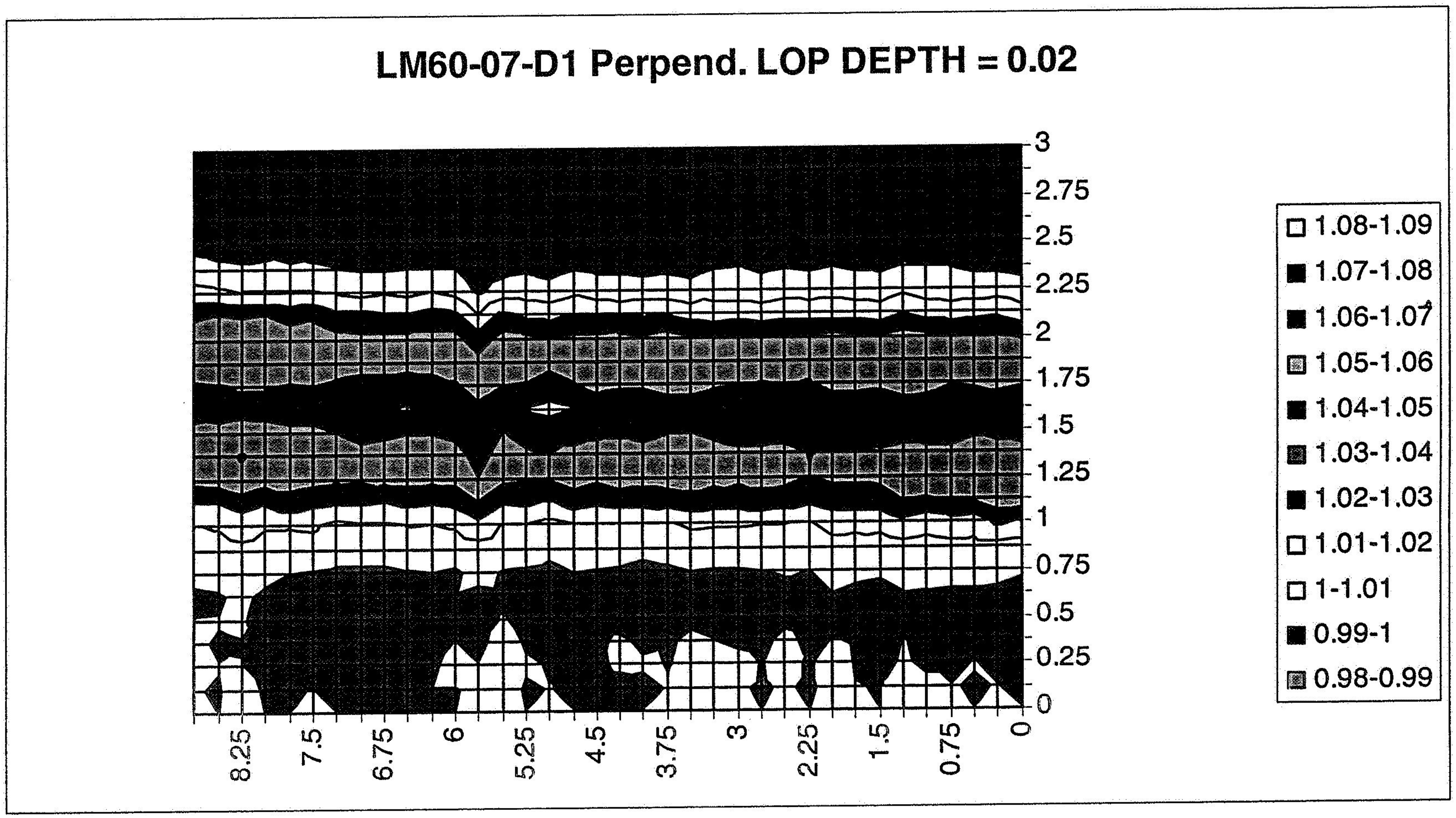
# Normalized 2-Dimensional MWM Image of Specimen LM60-07-D1, at 250kHz, with MWM Longer Winding Segments Perpendicular to Weld Axis



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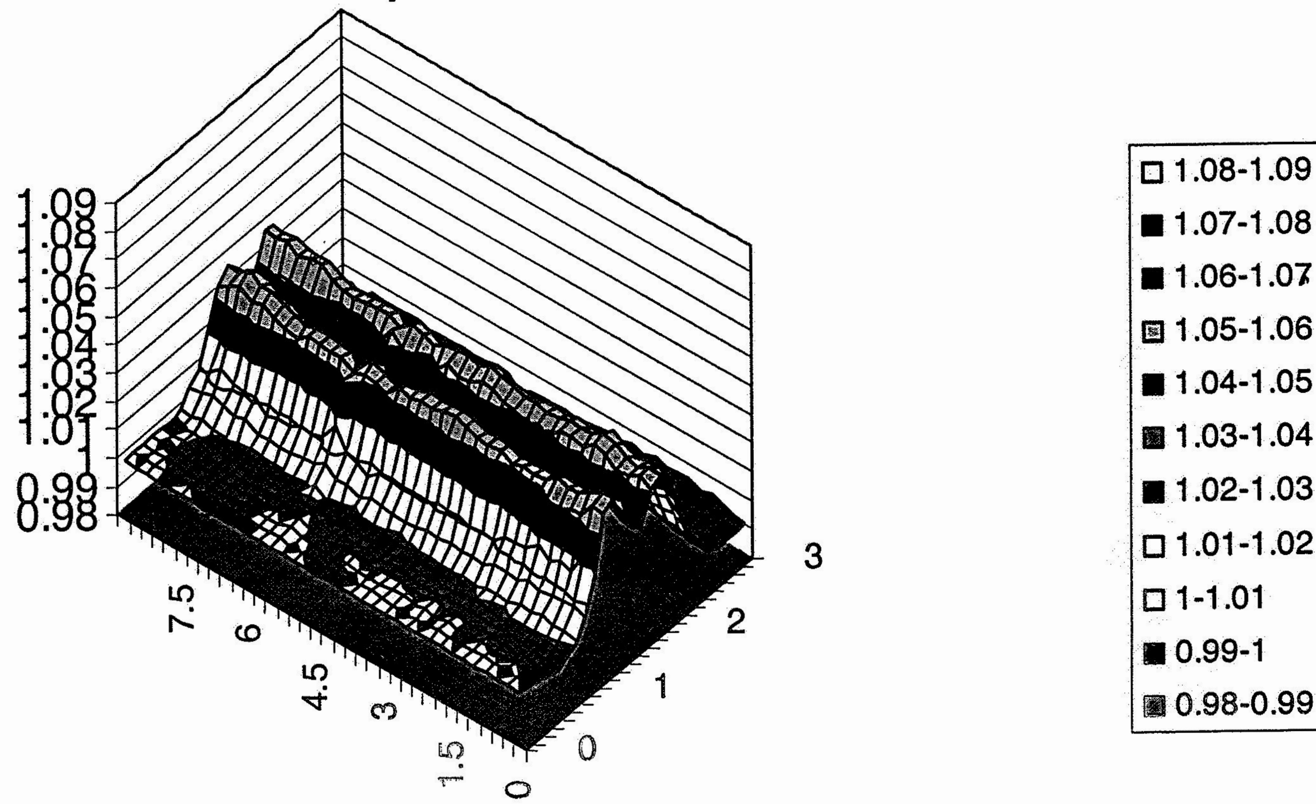
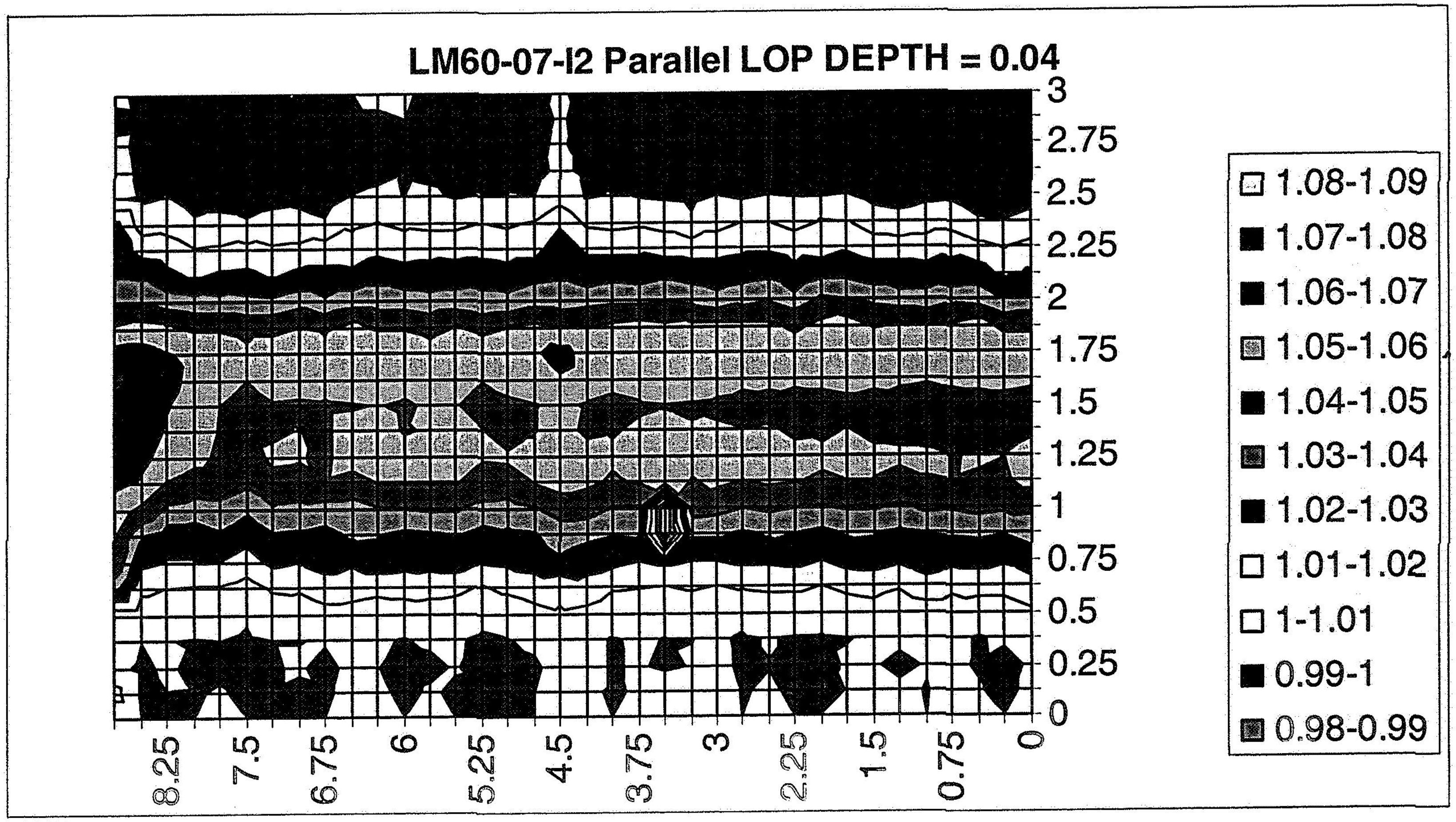
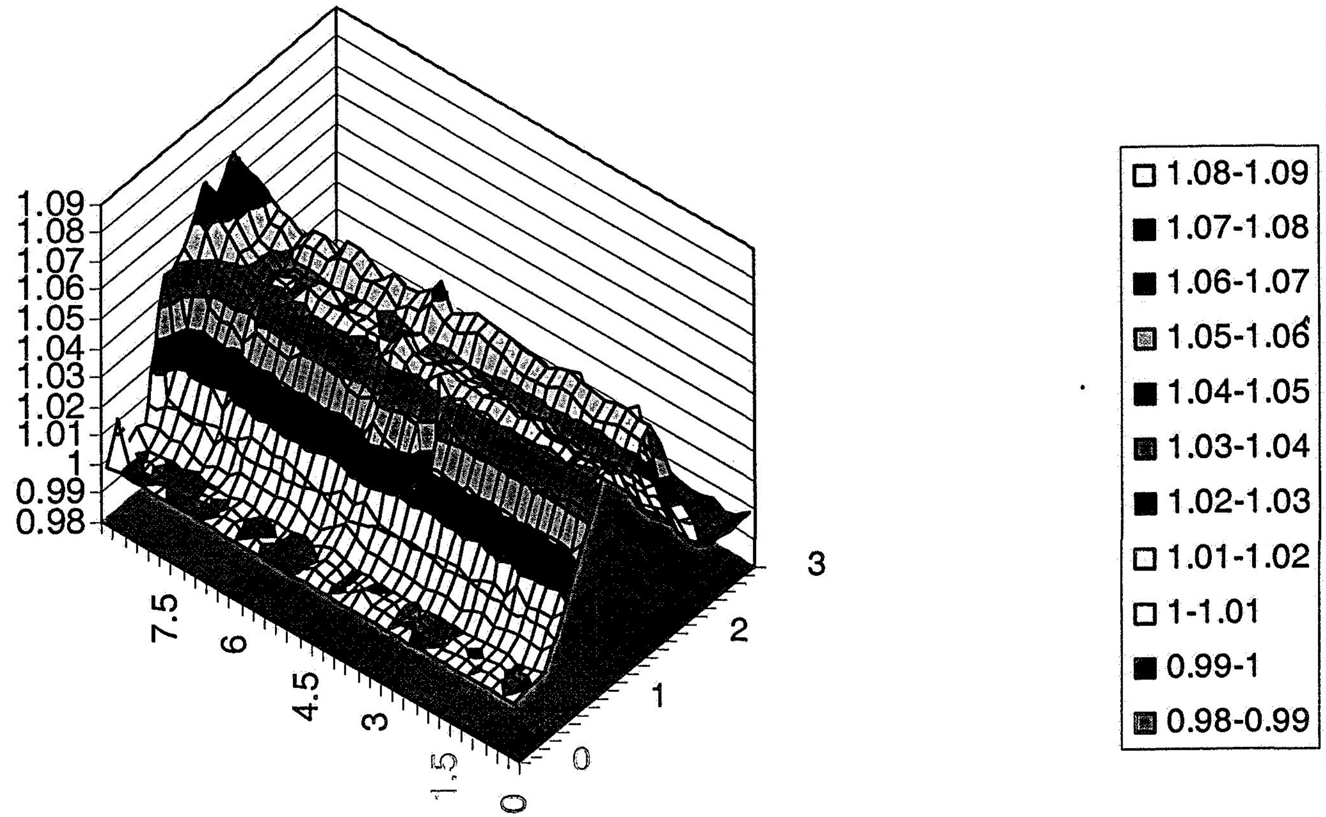
# Normalized 2-Dimensional MWM Image of Specimen LM60-07-D1, at 250kHz, with MWM Longer Winding Segments Perpendicular to Weld Axis



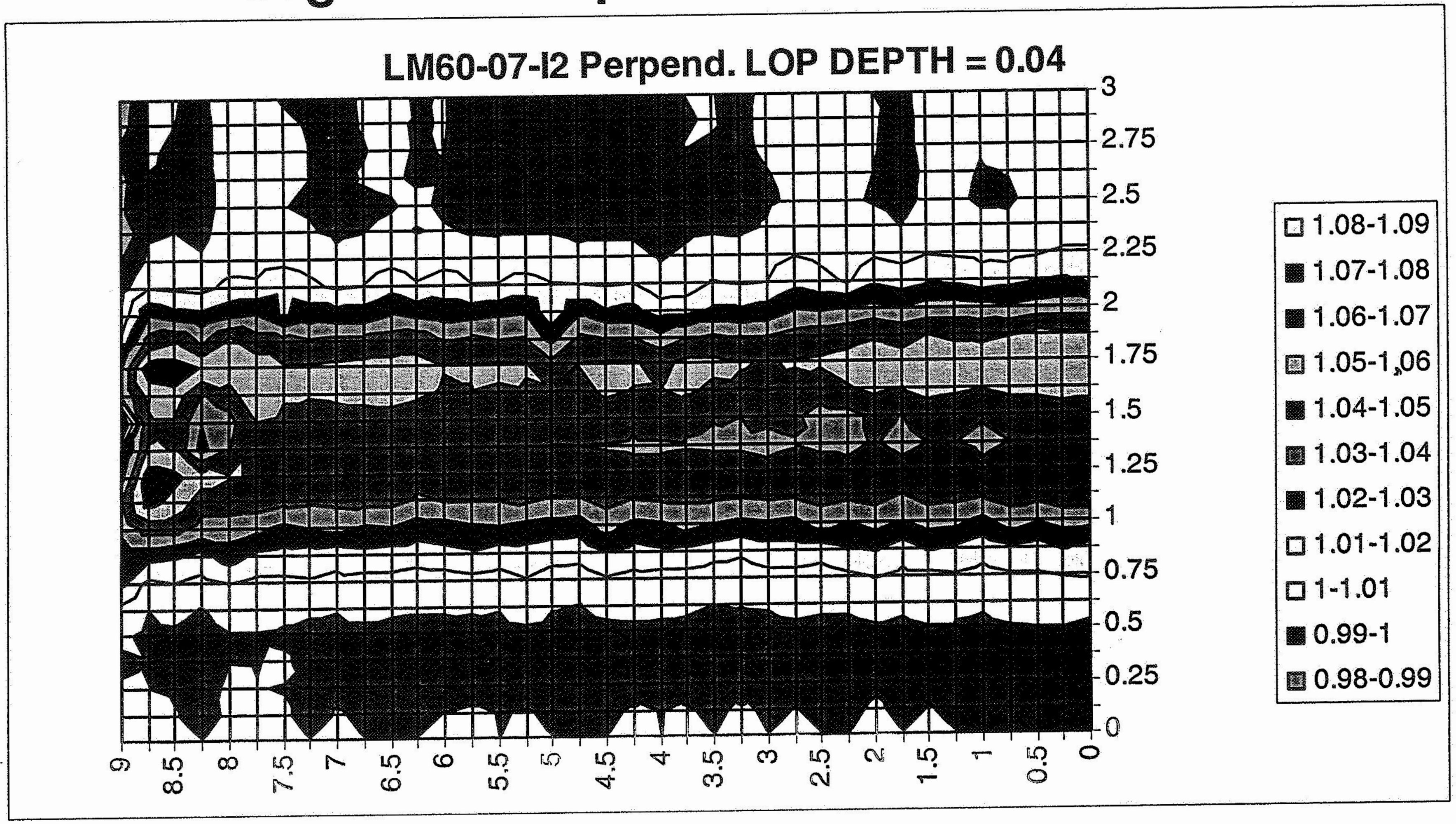
# Normalized 2-Dimensional MWM Image of Specimen LM60-07-I2, at 250kHz, with MWM Longer Winding Segments Parallel to Weld Axis



# Normalized 2-Dimensional MWM Image of Specimen LM60-07-I2, at 250kHz, with MWM Longer Winding Segments Parallel to Weld Axis



# Normalized 2-Dimensional MWM Image of Specimen LM60-07-I2, at 250kHz, with MWM Longer Winding Segments Perpendicular to Weld Axis







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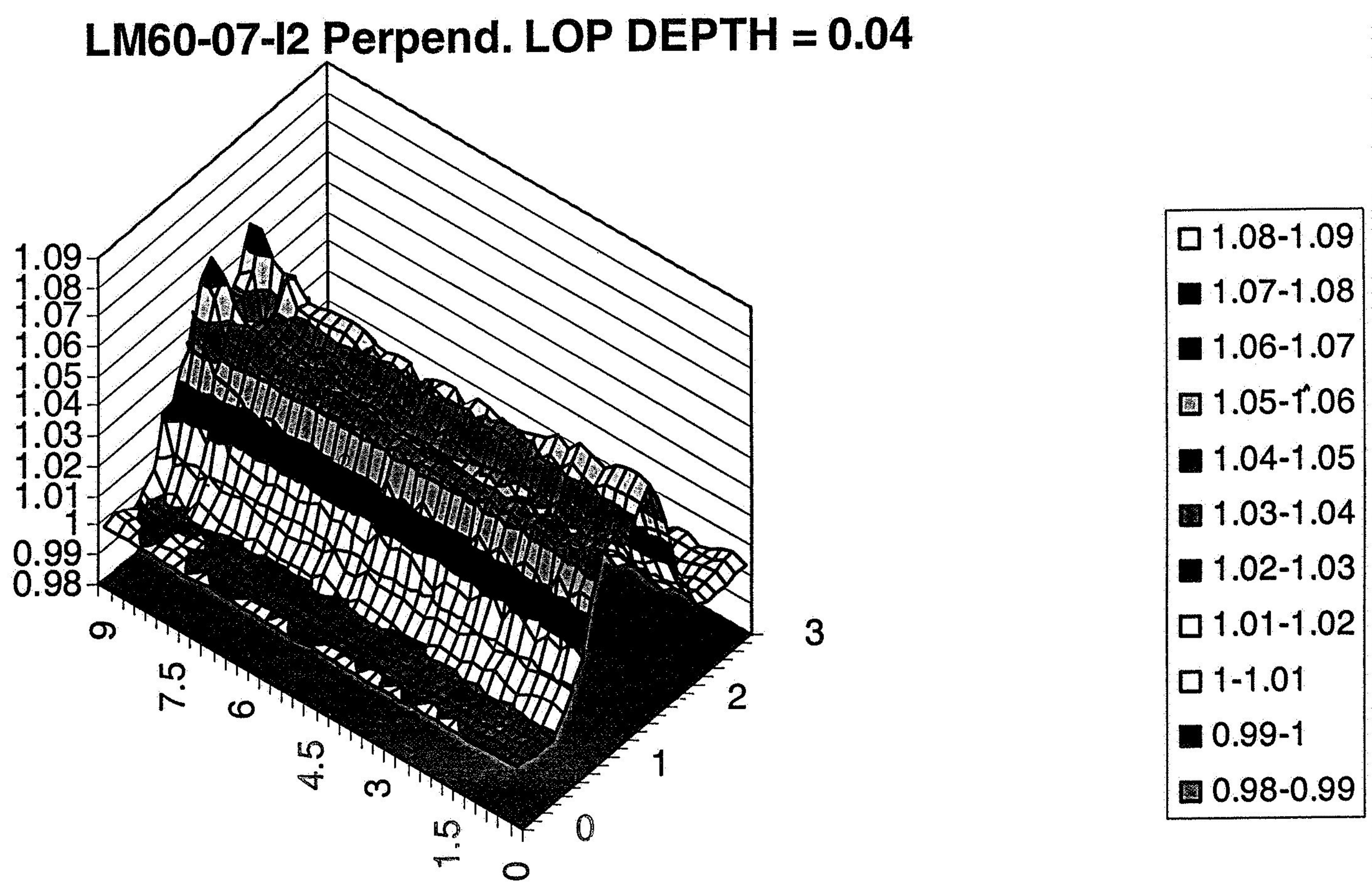
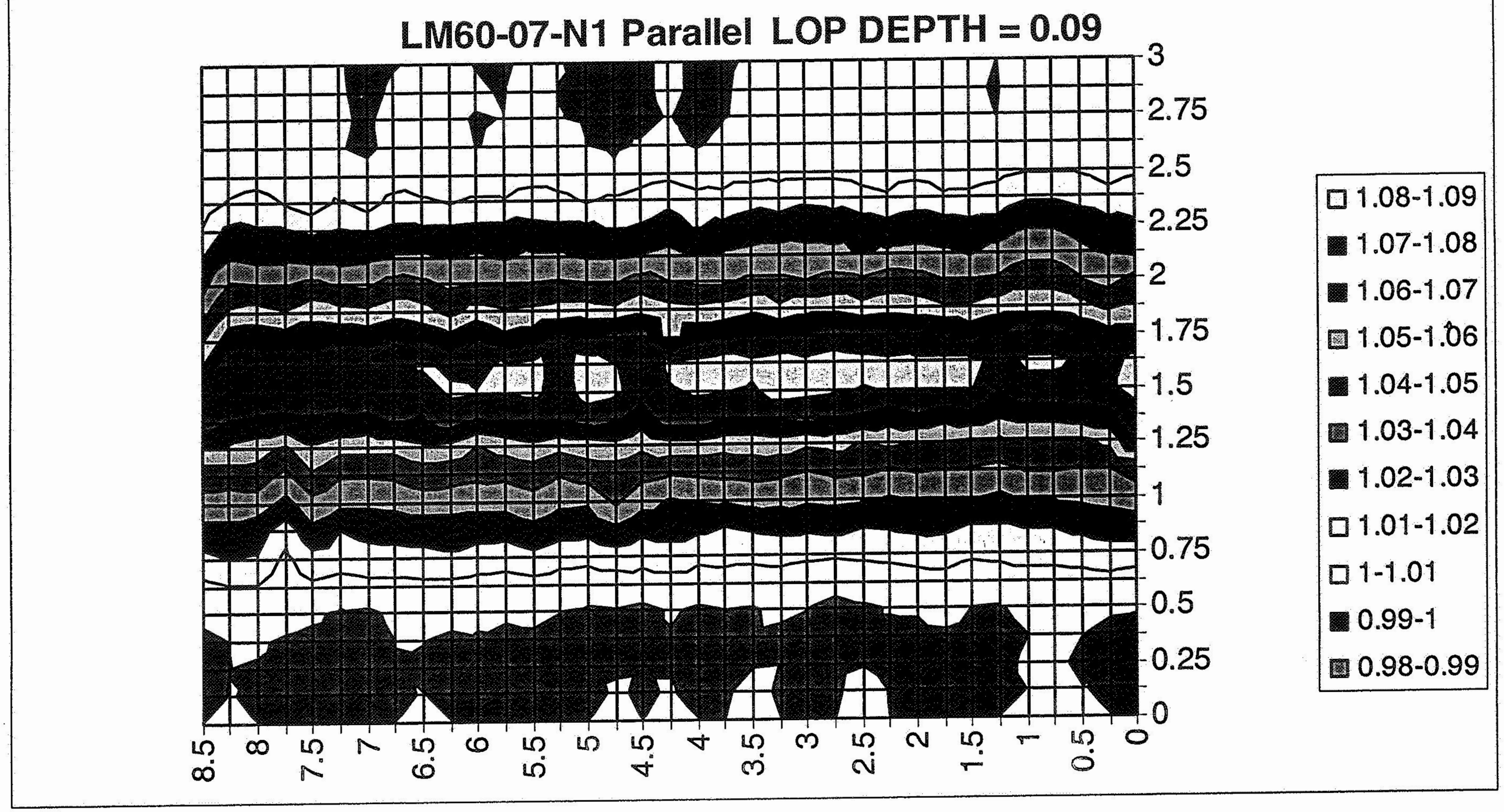
# Normalized 2-Dimensional MWM Image of Specimen LM60-07-I2, at 250kHz, with MWM Longer Winding Segments Perpendicular to Weld Axis

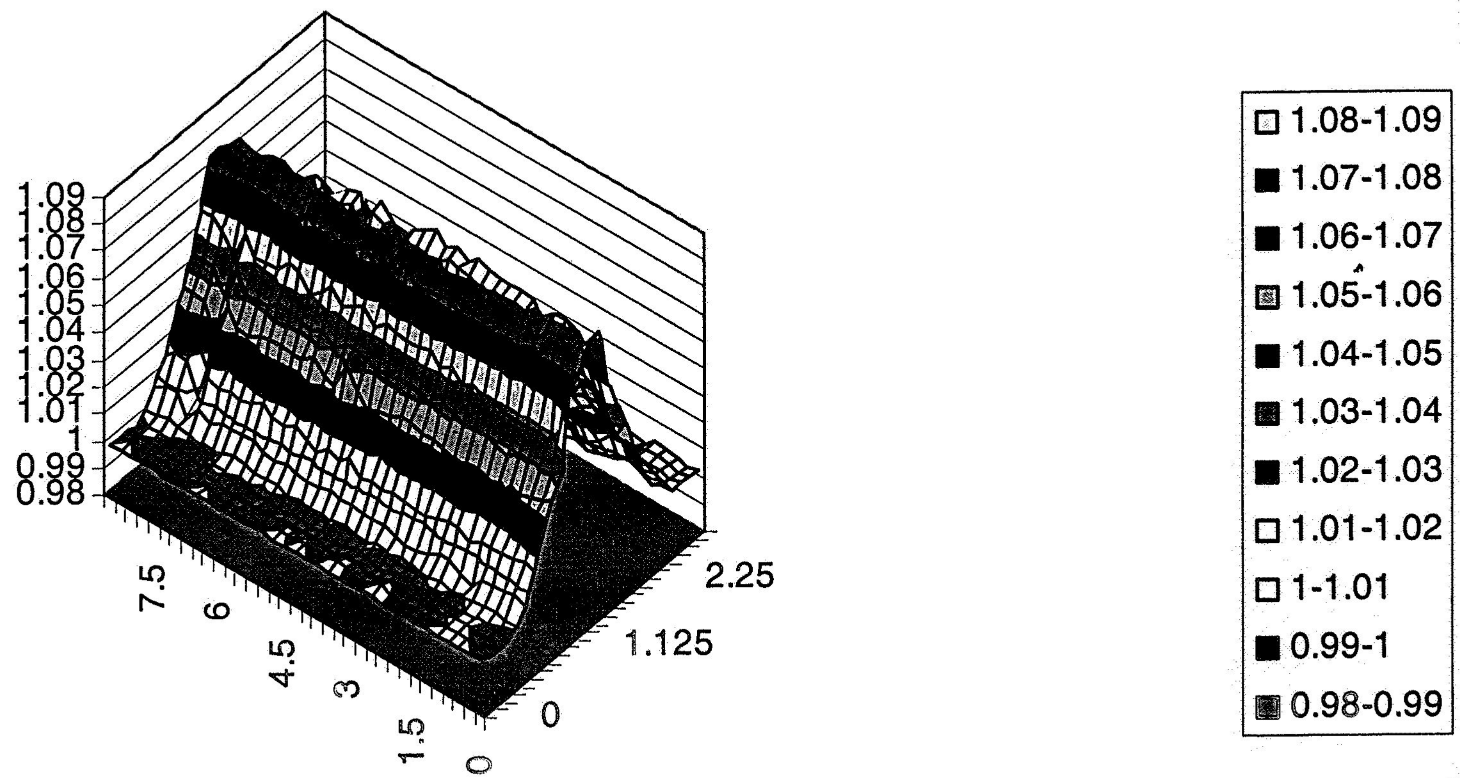


# Normalized 2-Dimensional MWM Image of Specimen LM60-07-N1, at 250kHz, with MWM Longer Winding Segments Parallel to Weld Axis

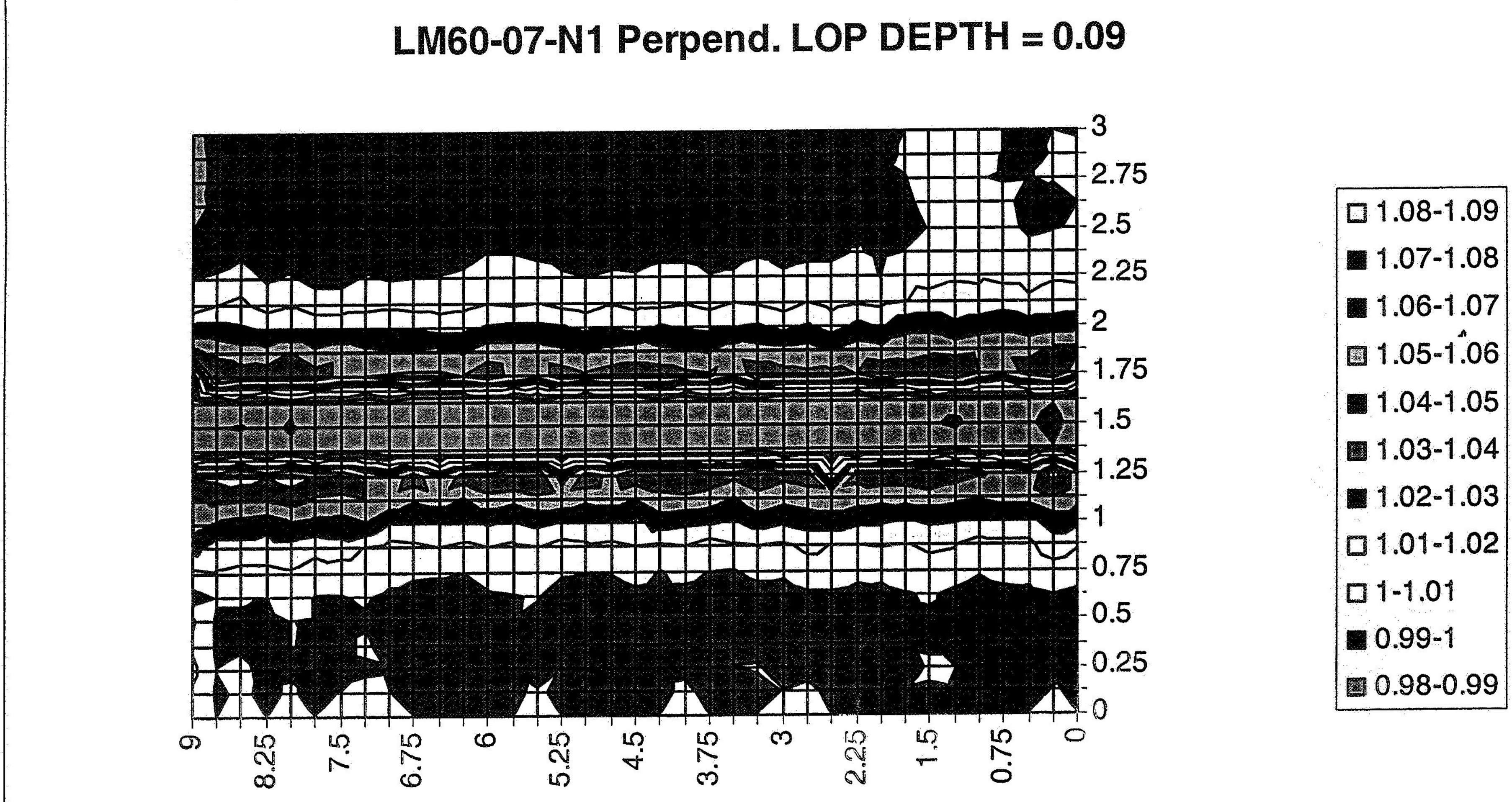


# Normalized 2-Dimensional MWM Image of Specimen LM60-07-N1, at 250kHz, with MWM Longer Winding Segments Parallel to Weld Axis

LM60-07-N1 Paralle LOP DEPTH = 0.09



# Normalized 2-Dimensional MWM Image of Specimen LM60-07-N1, at 250kHz, with MWM Longer Winding Segments Perpendicular to Weld Axis







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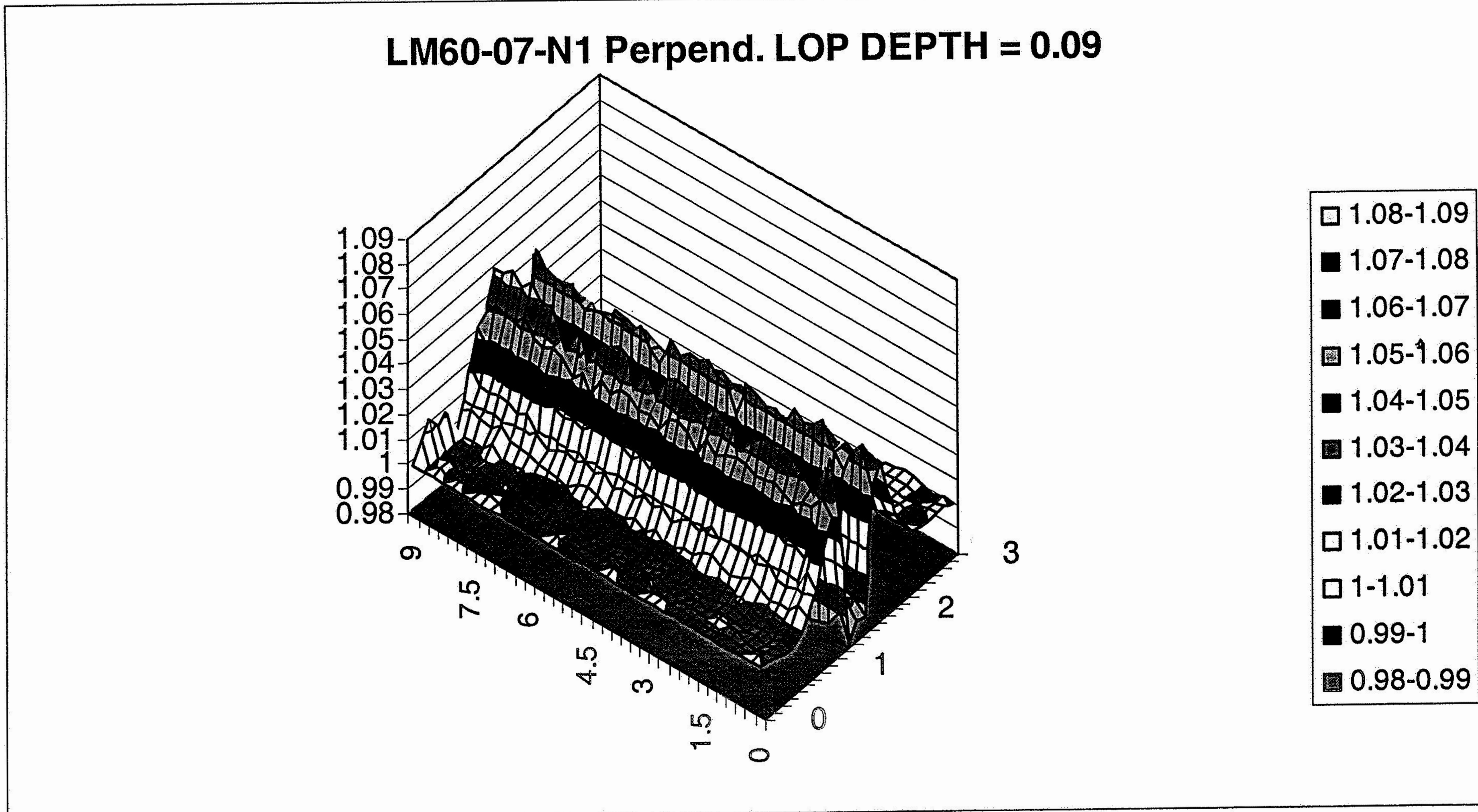

# Conclusions

- JENTEK has demonstrated capability to discriminate between LOP defect thickness of 0.02, 0.04 and 0.09 in.
- Sensitivity to LOP defect thickness is due to a correlation with microstructural changes that affect the near surface electrical conductivity within the first 0.01 inches
- JENTEK has demonstrated capability to detect cracks within AFSW